SECTION 9.4

# Water Treatment

## Key Terms

temporary hardness
permanent hardness
desalination
potable water
reverse osmosis

Ontario is fortunate to have abundant fresh water. However, Ontario also has examples of how pollution can make fresh water unfit for drinking. In May 2000, one of the wells that supply drinking water for the town of Walkerton was contaminated by run-off from a nearby farm. This run-off contained *E. coli* bacteria from animal manure. Water from the well was not tested or processed properly. As a result, the bacteria killed seven people and made about 2500 other people seriously ill.

In 1962, Reed International in Dryden, Ontario, began using a mercury cell process to make bleaching chemicals for its pulp and paper plant, shown in **Figure 9.16**. The company dumped waste water that contained mercury from this process directly into the Wabigoon-English River system. Within a few years, residents of the two closest communities downstream, Grassy Narrows and Whitedog, were showing signs of mercury poisoning from eating fish from the river. In 1970, commercial fishing on the river was stopped and some tourism businesses were shut down because of the extensive mercury contamination. Research published in 2010 found that mercury pollution is still having effects on the health of the people in Grassy Narrows and Whitedog. Even children born 30 years after the plant closed are showing clear signs of mercury poisoning.

In this section, you will explore chemical and physical methods for making water safe to drink.

**Figure 9.16** Between 1962 and 1970, Reed International dumped over 9000 kg of mercury into the Wabigoon-English River system.

## Treating Water Hardness

As described in Section 9.3, hard water contains dissolved calcium and magnesium carbonates. Limestone, for example, reacts with rainwater that contains dissolved carbon dioxide:

$$CaCO_3(s) + H_2O(\ell) + CO_2(aq) \rightleftharpoons Ca(HCO_3)_2(aq)$$

**temporary hardness** hardness that can be removed from water by boiling

The double arrow in the chemical equation means that the reaction is *reversible*. When you read the equation from *right to left*, it describes dissolved calcium hydrogen carbonate forming calcium carbonate precipitate, water, and carbon dioxide gas. This reverse reaction takes place when hard water is heated. Calcium hydrogen carbonate and magnesium hydrogen carbonate are the main causes of **temporary hardness** in water.

## Temporary Hardness and Permanent Hardness

Temporary hardness can be removed from water by boiling. Boiling drives most of the dissolved carbon dioxide out of the solution. Without dissolved carbon dioxide, the calcium carbonate that forms cannot react to form calcium hydrogen carbonate. So, the calcium carbonate precipitates out of the solution. **Figure 9.17** shows calcium carbonate and magnesium carbonate deposits that have been precipitated by heating hard water. While boiling water to remove temporary hardness is a simple solution, it is not practical for large volumes of water. The inside of large hot water boilers, for example, would soon become encrusted with calcium carbonate and magnesium carbonate deposits.

**permanent hardness** hardness that cannot be removed by boiling

**Permanent hardness** is usually caused by dissolved calcium sulfate, $CaSO_4(aq)$, and magnesium sulfate, $MgSO_4(aq)$, which cannot be removed by boiling. However, permanent hardness can be removed by chemical methods. The least expensive water-softening chemical is washing soda, which is the common name for hydrated sodium carbonate, $Na_2CO_3 \cdot 10H_2O$. The addition of sodium carbonate to hard water precipitates insoluble magnesium and calcium carbonate. The following equation represents the reaction between calcium sulfate and sodium carbonate:

$$CaSO_4(aq) + Na_2CO_3(s) \rightarrow CaCO_3(s) + Na_2SO_4(aq)$$

However, the addition of sodium carbonate makes water basic. Ion-exchange water softeners use a system that avoids making the water basic.

**Figure 9.17** Deposits of calcium carbonate and magnesium carbonate on water-heating elements can reduce the heater's efficiency.

## Ion-Exchange Water Softeners

An ion-exchange water softener, like the one in **Figure 9.18**, exchanges the ions that cause hard water, principally calcium and magnesium, for sodium ions. Dissolved sodium compounds do not form a precipitate when the water is heated, and they do not form insoluble substances with soap.

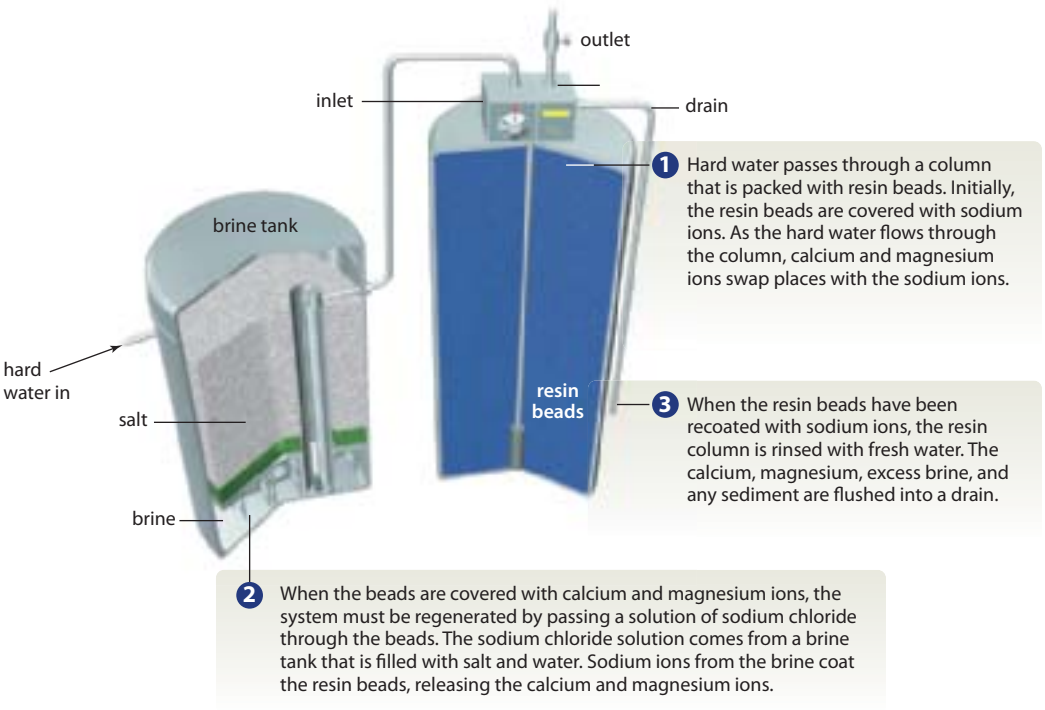


**Figure 9.18** Water softened by an ion-exchange softener contains a high concentration of sodium ions. People on a low-sodium diet should avoid drinking water from a sodium ion water softener.

***Explain** the benefits and disadvantages of a home water softener.*

## Desalination

**desalination** the process of obtaining fresh water from salt water

**potable water** water that is safe to drink

Most of the water on Earth's surface is too salty to drink. Dissolved ions regulate the flow of substances in and out of our cells. When someone drinks salt water, the ion balance is upset and water flows out of the cells. The cells become dehydrated. The more salt water that a person drinks, the worse the dehydration of the cells becomes. Excess salt is also harmful to many plants. The process of obtaining fresh water from salt water is called **desalination**. Water that is safe to drink is called **potable water**.

### Distillation

Most of the world's desalination plants are located in the Middle East. The majority of Middle East desalination plants distill ocean water, like the plant shown in **Figure 9.19**. Ocean water is heated and the vapour, which is free from dissolved substances, is condensed. Desalination plants in the Middle East use local supplies of relatively cheap oil to heat the water. Elsewhere in the world, however, energy costs usually make thermal desalination plants impractical. Even oil-rich countries, such as Saudi Arabia, are now developing desalination plants that use processes requiring less energy and that can be powered partly by solar energy.

**Figure 9.19** The Jubail desalination plant, on the Arabian Gulf in Saudi Arabia, is the largest desalination plant in the world. Some of the energy that is needed to boil the water comes from waste heat from an adjacent electrical power plant.

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### Reverse Osmosis

**reverse osmosis** the process of using high pressure to force water from a concentrated solution through a semi-permeable membrane to get a less concentrated solution

A more energy-efficient process for producing potable water is **reverse osmosis.** Osmosis is the natural tendency of a solvent, such as water, to move through a semi-permeable membrane to make the concentrations of solutes on both sides of the membrane equal. Water can pass through the semi-permeable membrane, but solutes, such as salt, cannot. If a semi-permeable membrane separates two aqueous solutions with different concentrations, water will flow from the more dilute solution into the more concentrated solution until there is no longer a difference in concentration. In reverse osmosis, high pressure is applied to the more concentrated solution to force water through the semi-permeable membrane in the opposite direction.

### Reverse Osmosis Desalination Plants

Large reverse osmosis desalination plants, such as the one shown in **Figure 9.20**, are usually built in coastal areas where ocean water can be easily taken into the plant. Only part of the water taken in is purified. The rest, which contains dissolved salt and other impurities, is returned to the ocean with no added chemicals and no thermal pollution.

The largest seawater desalination plant in North America is located on Tampa Bay in Florida. This plant uses reverse osmosis to produce up to 100 million litres of potable water daily.

**Figure 9.20** High pressure forces water across a semi-permeable membrane inside these vessels. The water that passes through the membranes is completely free of salt and other ions.

## Water Supply Treatment

Birth and death records can provide an overview of the health of a population. The first collection of such data was made in the middle of the 17th century in London, England. The average life expectancy for a Londoner was then about 27 years. The graph in **Figure 9.21** shows data for life expectancy in North America. Many health scientists have concluded that the increasing life expectancy, since around 1800, is due mostly to the widespread improvement in the quality of water supplies, especially in towns and cities.

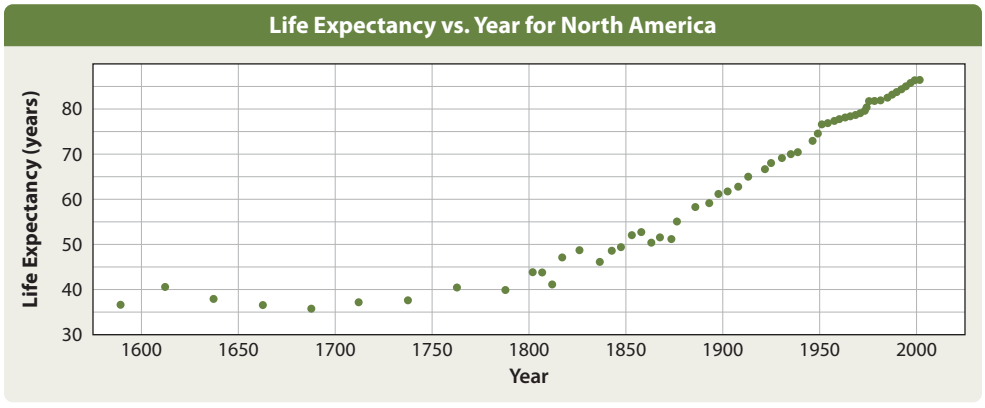


**Figure 9.21** Life expectancy in North America has increased steadily since 1800, partly because of improvements in water treatment.

***Analyze*** *Which century had the greatest increase in life expectancy?*

## Municipal Water Treatment

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**Figure 9.22** gives an overview of the processes that are used by municipalities to treat drinking water. In general, water enters a treatment plant from a surface source, such as a lake, river, or reservoir, or from a ground water source, such as a well or spring. On its way to the storage tower, the water is filtered, treated with chemicals to remove suspended particles, and treated with chlorine or ozone to kill harmful bacteria. After treatment, the water is tested to make sure that it is safe and meets current water standards.

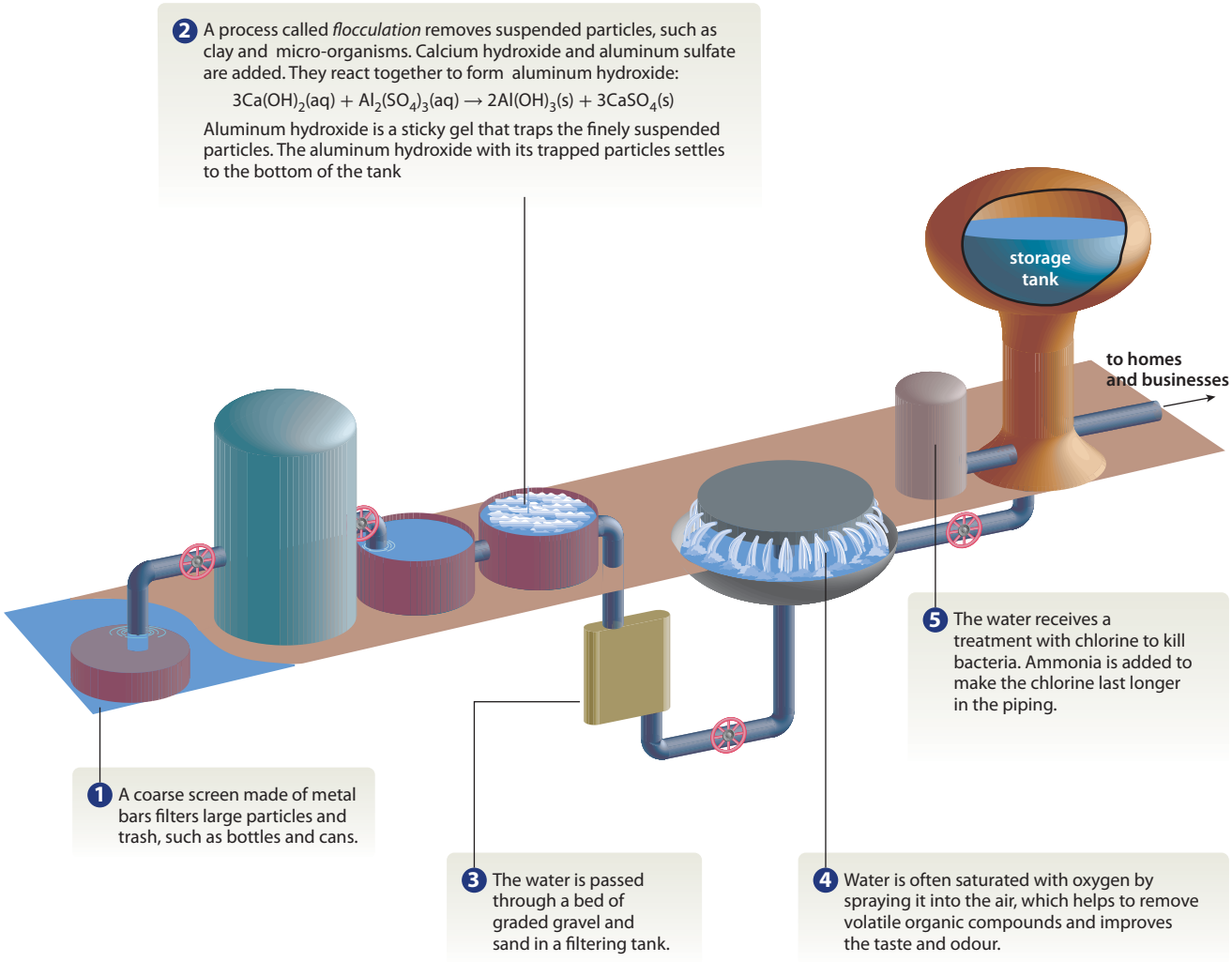



**Figure 9.22** Municipalities use a combination of physical and chemical processes to purify water.

### Learning Check

**19.** How does temporary water hardness differ from permanent hardness?

**20.** Why must salt be added, from time to time, to a home water softener?

**21.** **Figure 9.19** shows a seawater desalination plant located next to an oil-burning electrical generating plant. What are the advantages of this arrangement?

**22.** Why are there are no large commercial desalination plants in Canada?

**23.** What evidence suggests that water treatment is an enormous benefit to society?

**24.** What are the basic steps in treating water for a municipal water supply?

## Waste-Water Treatment

In most towns and cities, the water that is used in homes and businesses is collected by a system of pipes and sewers that carries it to a waste-water treatment plant, like the one shown in **Figure 9.23**. The goal of municipal waste-water treatment is to remove solids, chemicals, and dangerous bacteria from sewage. The waste water can then be released back into the environment.

**Figure 9.23** Waste-water treatment plants remove possible pollutants from sewage so that those pollutants cannot enter and harm the environment.

**Suggested Investigation**

Inquiry Investigation 9-D, Treating Waste Water

Waste water (or sewage) first passes through screens that are made of closely spaced metal bars. These screens remove large solids and garbage that could block the flow through the machinery. The subsequent treatment of sewage often has three stages, as shown in **Figure 9.24**. Depending on their needs, municipalities use one, two, or all three of these stages.

- *Primary treatment* in a holding tank removes solid materials by sedimentation and by skimming scum from the surface of the water. The addition of calcium hydroxide and aluminum sulfate causes a sticky aluminum hydroxide precipitate to form:

$$3Ca(OH)_2(aq) + Al_2(SO_4)_3(aq) \rightarrow 2Al(OH)_3(s) + 3CaSO_4(s)$$

  The precipitate settles slowly, removing suspended particles and some bacteria.
- *Secondary treatment* uses natural micro-organisms that feed on organic matter in the sewage. These bacteria convert organic material into carbon dioxide, water, and nitrogen compounds.
- *Tertiary treatment* involves chemical precipitation of nitrogen, phosphorus, and organic compounds.

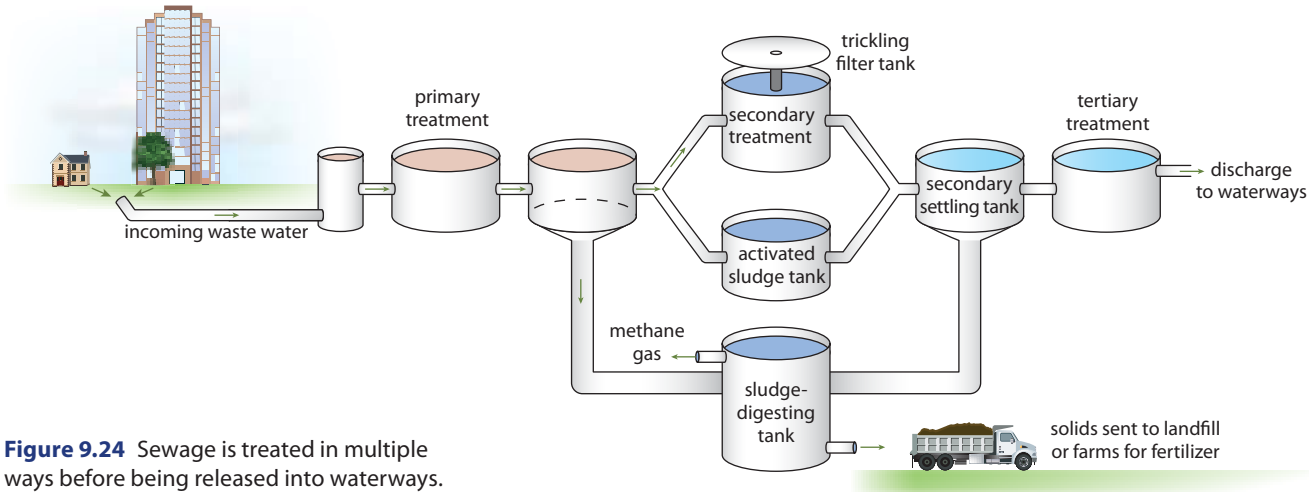



**Figure 9.24** Sewage is treated in multiple ways before being released into waterways.

## Section 9.4 REVIEW

### Section Summary

- Temporary water hardness is due to dissolved calcium carbonate and magnesium carbonate, and can be removed by boiling the water.
- Permanent water hardness is usually due to dissolved calcium sulfate and magnesium sulfate, and cannot be removed by boiling the water.
- Potable water can be produced from seawater or polluted water by various technologies, including distillation and reverse osmosis.
- Municipal water treatment plants process water to meet provincial standards, thus ensuring that the water is safe to drink.
- Waste-water treatment plants reduce pollutants and micro-organisms to levels that are low enough for the water to be safely returned to the environment.

### Review Questions

**1.** K/U Hard water scale is caused by the build-up of calcium carbonate and magnesium carbonate.
   **a.** List the appliances in your home that are most likely to be affected by hard water scale.
   **b.** How can you remove hard water scale from an appliance?

**2.** T/I Why is lime scale more likely to form on hot-water pipes than on cold-water pipes?

**3.** T/I When people dump chemicals and waste into waterways, it is harmful to the environment. However, people also dump chemicals into water when they are purifying it for use. Explain the difference between these two situations.

**4.** T/I How many sodium ions are exchanged for each calcium ion in a water softener? Explain your answer.

**5.** T/I Energy from the Sun can be used to heat water, especially in areas that receive plenty of sunshine. Why do you think the desalination plant shown in **Figure 9.19** uses oil, rather than the Sun's energy?

**6.** T/I What by-products are produced by a distillation desalinization plant?

**7.** A Could a reverse-osmosis filter system be used to soften hard water? If so, would it have any advantage over an ion-exchange water softener?

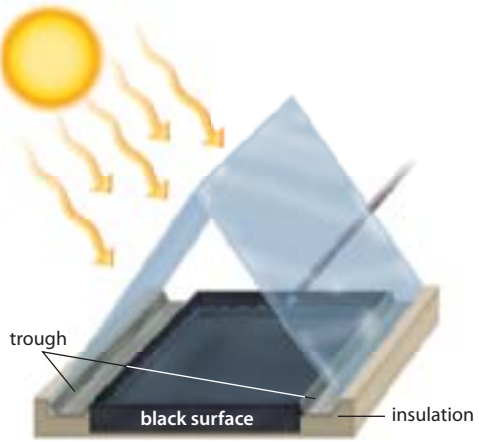
**8.** K/U Briefly describe the physical processes that are used to clean municipal waste water.

**9.** K/U Aeration is the process of dissolving oxygen in water. Describe how aeration can help to purify water.

**10.** K/U Which water purification processes at a water treatment plant do not take place in nature?

**11.** A Due to the cost, not all municipalities use tertiary treatment to purify waste water. What would be the potential threat to aquatic life if water was discharged into a lake without tertiary treatment?

**12.** C The following diagram shows a simple solar distillation apparatus. Draw a sketch that explains how this apparatus produces potable water.




**13.** A Pickling is a food preservation technique that uses salt to dehydrate food to make the food inhospitable to bacteria. The food is then stored in an acid solution that further inhibits bacterial growth. How does a concentrated salt solution help the pickling process?

**14.** K/U Name two different household wastes, and the substances they contain that should be removed at a waste-water treatment plant.

**15.** T/I An advertisement for a magnetic water conditioner claims that it can alter calcium ions so they cannot cause lime scale. Outline an investigation you could perform to test whether this claim is true.

**16.** A Lead(II) ions can be present in water that has passed through lead pipes or through pipes joined using lead-tin solder.
   **a.** Identify a compound that could be used to precipitate lead from an aqueous solution.
   **b.** Write the net ionic equation for the reaction.